10/565405
IAP15 Rec'd PCT/PTO 23 JAN 2006

APPLICATION FOR UNITED STATES LETTERS PATENT

for

Method for Bispectral Picking Anelliptical
NMO Correction Parameters

by

Risto Siliqi
29, rue Saint-Andrè des Arts
75006 Paris
France
Citizenship: French

David M. Ostfeld, Reg. No. 27,827
Attorney for Application

Docket No.: 10431-13

Mail all correspondence to:
David M. Ostfeld
Adams and Reese LLP
4400 One Houston Center
1221 McKinney
Houston, Texas 88010
(713) 308-0128

10/565405
JAP15 Rec'd PCT/PTO 23 JAN 2006

METHOD FOR BISPECTRAL PICKING OF ANELLIPTICAL NMO CORRECTION PARAMETERS

The field of this invention is seismic prospecting. The invention relates particularly to processing of seismic traces in a common midpoint gather.

The invention is more precisely related to a method of determining velocity V and anellipticity η parameters necessary to perform processing including NMO correction of seismic traces.

Seismic prospecting usually consists of emitting seismic waves in the subsoil using one or several seismic sources, and making surface records of seismic data corresponding to seismic waves reflected on geological interfaces in the subsoil as a function of time (also called reflectors) using receivers (also called geophones or hydrophones) depending on whether the prospecting is being done on land or at sea) and then processing these data to extract useful information about the geology of the subsoil.

The record of the seismic energy produced by each receiver during data acquisition is called a seismic trace.

One conventional technique for seismic prospecting is multiple coverage, in which sources and receivers are arranged such that several seismic traces are grouped together at the same midpoint (in other words the point at equal distance between the source and the receiver for a given trace).

Although seismic traces contain useful information about seismic reflections and geology of the subsoil, they also contain noise components.

One of the first purposes of the processing of seismic data is to eliminate, or at least attenuate, these unwanted noise components such that the useful information can be clearly identified and interpreted.

One conventional method used to attenuate these noise components is Common MidPoint (CMP) gather. Traces with the same midpoint are then grouped as a function of the distance between the source and the receiver (called the offset).

In general, representation of seismic data in images requires the use of processing including:

- a so-called TZO (Transform to Zero Offset) operation designed to compensate for the NMO effect of paths by correcting the arrival time of reflections to the arrival time of traces with zero offset,
- and a migration operation designed to reproduce the correct shapes of the geological interfaces.

Although these TZO and migration operations are usually carried out one after the other, they can be carried out jointly. This is the case particularly when a time migration is done before stack (PSTM - Pre-Stack Time Migration).

In a simplified manner, the TZO operation simulates acquisition of seismic data by sources and receivers placed at the common mid-point.

The purpose is to add records illuminating the same point in the subsoil to increase the signal to noise ratio and the primary reflections to secondary reflections ratio, and thus benefit from the advantages of "multiple coverage".

In order to make a zero offset image, a so-called obliqueness correction method or NMO (Normal Move Out) correction method is used.

If it is assumed that the subsoil is horizontally stratified with no lateral variation of the propagation velocities, it can be shown that records that have the property of illuminating the same point in the subsoil are records that have the same midpoint.

However, the image of a reflection in the subsoil arrives at variable times depending on the offset. Therefore, in order to stack reflections, it is necessary to start by correcting the various records to bring them all to a common zero offset reference.

Historically, the NMO correction is based on a particularly simple model of the subsoil; a homogeneous model with horizontal reflectors.

In this model, reflections associated with each subsoil reflector are theoretically aligned along hyperbolas also called indicators, centred vertically above the midpoint.

The arrival time of a reflection is then a hyperbolic function of the source-receiver offset, the shortest time being obtained at zero offset.

In order to stack records in each gather, the NMO correction straightens the hyperbolas until they are theoretically horizontal.

The NMO correction is then made based on the following hyperbolic equation for the travel time t after reflection, associated with a source-receiver offset x pair:

$$t^2 = t_0^2 + \left(\frac{x}{V}\right)^2$$

in which t_0 represents the zero offset travel time and V denotes the average propagation velocity of waves in the subsoil.

The simplistic model mentioned above is based particularly on assumptions such as low angles of incidence and an isotropic medium.

But assumptions made for the simplistic model are too restrictive to describe a complex medium, and in particular cannot be applied to the propagation of seismic waves in an anisotropic medium (medium in which the velocity of waves can vary depending on the propagation direction).

The use of a less simplistic model is necessary, particularly due to:

- the use of long streamers for acquisition in deep offshore, which in particular means that traces with far offsets are acquired;
- observation of anisotropy in clayey type sediments.

The generally accepted assumption consists of modelling an anisotropic medium as a stack of transversely isotropic layers with a vertical axis of

symmetry. This is known as Vertical Transverse Isotropy (VTI).

Thus, it has been proposed to determine NMO corrections to be made by:

- introducing vertical non-homogeneity into a homogenous VTI medium model, as presented in the document "ALKHALIFAH T. and TSVANKIN I., 1995, Velocity analysis for transversely isotropic media: Geophysics, 60, 1550-1566";

or by

- introducing VTI anisotropy into a model with stratified isotropic layers, as demonstrated in document "SILIQI R. and BOUSQUIE N., 2000, Anelliptic time processing based on an offset hyperbola approach, 70th Ann. Internat. Mtg.: Soc. Of Expl. Geophys., 2245-2248".

This second approach combining vertical non-homogeneity and VTI anisotropy to give a new model of the subsoil, appears to be the best approach in most real cases studied.

The following equation for correction of the travel time t after reflection, using an anelliptic offset hyperbola, associated with a source - receiver offset x pair, is derived from this model:

$$t(V,\eta) = \frac{8\eta}{1+8\eta} t_0 + \sqrt{\left(\frac{t_0}{1+8\eta}\right)^2 + \frac{x^2}{(1+8\eta)V^2}} \quad \text{Equation (1a)}$$

where V is the velocity conventionally used in seismic corresponding to small offsets and η is a parameter, called the anellipticity parameter.

The document "SUAUDEAU E. and SILIQI R., 2001, Anelliptic pre-stack time migration, Annual International Meeting, CSEG Expanded Abstracts" also proposes to include the NMO correction by anelliptic offset hyperbola

in the equation for the path time used during the PSTM migration operation.

The PSTM migration equation is conventionally expressed in the form of a double anelliptic offset hyperbola, which is the sum of two square roots (the Double Square Root (DSQR) equation).

Taking account of anellipticity, the expression for this constant offset equation, becomes:

$$t = \frac{8\eta}{1+8\eta}t_0 + \sqrt{\left(\frac{t_0/2}{1+8\eta}\right)^2 + \frac{(x-x_m+h)^2}{(1+8\eta)V^2}} + \sqrt{\left(\frac{t_0/2}{1+8\eta}\right)^2 + \frac{x-x_m-h)^2}{(1+8\eta)V^2}}$$

Equation (1b)

where:

- the V and η parameters are those mentioned above,
- x_m is the coordinates of the midpoints,
- $x - x_m$ represents the migration aperture,
- h is the half source-receiver offset,
- t_0 is the double time for zero aperture of the operator.

Note that when the aperture $x - x_m$ of the migration is zero, the PSTM correction equation (1b) becomes the NMO correction equation (1a). Thus, the NMO correction forms a special case of the PSTM migration; the case of PSTM migration with zero aperture.

Therefore, finally, in order to perform seismic data processing including NMO correction taking account of vertical heterogeneity and VTI type anisotropy, it is necessary to determine the velocity V and anellipticity η parameters.

The said parameters V and η can conventionally be estimated by carrying out two passes such that:

- during the first pass, the distribution of velocities V along the time axis is estimated, only using data with near offsets;

- during the second pass, the anellipticity η is estimated along the time axis, using:

  - the distribution of velocities determined during the first pass, and

  - all data (including data with far offsets).

The document entitled:

"SILIQI R., 2001, Technological leap in time processing focuses the data throughout anisotropic media: First Break, 19, No.11, 612-618",

has also demonstrated that the parameters V and η can be estimated in a single pass, during which bispectral analyses are carried out in order to simultaneously pick the V and η parameters along the time axis, using all data.

However, dense analyses of NMO correction parameters are preferably made when the correction equation no longer depends on the time t_0 (we then talk about static NMO correction).

A static correction effectively provides a means of offsetting all samples each forming traces of the same time δt, for a given offset.

Thus, when a static correction is made, the number of calculations to be made can be significantly reduced and the trace stretching phenomenon is eliminated, which makes the said dense analyses viable.

At the moment, the only way to make velocity and anellipticity analyses is to use two passes, in particular making use of parabolic approximations of NMO

residuals, in order to obtain a dense picking of the V and η parameters.

In this context:

- the first step is to estimate residual velocities, using near offset data, according to a first estimate of velocities;

- the next step is to estimate anellipticity on all data, using velocity updates done previously.

A mute law must also be defined to estimate residual velocities, so as to only keep data that are considered as being near offset data.

However, the efficiency of the two-pass analysis is particularly sensitive to the choice of such a mute law.

On the other hand, the anellipticity η is estimated mainly making use of far offset data.

But, the anellipticity estimate made for far offset data is not very precise, such that the correction made is finally inaccurate.

One purpose of the invention is to overcome these limitations and disadvantages, by proposing a processing including a static NMO correction which is more efficient and more precise.

More precisely, the purpose of the invention is a dense determination of velocity V and anellipticity η parameters in a single pass using all available data, in other words making use of all offset ranges.

To achieve this, the invention proposes a method of determining the velocity V and anellipticity η parameters for processing seismic traces from a common midpoint (CMP) gather including an anelliptic NMO correction, comprising:

- a preliminary step to define a plurality of nodes (dtn, τ_0), the said nodes being indicative of parameters dtn and τ_0 representing the NMO correction for the maximum offset and the zero offset travel time in hyperbolic coordinates, the said preliminary step being followed by

- for each node (dtn, τ_0) defined in the preliminary step, steps for the NMO correction of traces in the CMP gather as a function of the values of the said parameters dtn and τ_0 at the node considered, and for calculating the semblance function associated with the said NMO correction for the node considered; and

- for each picked time t_0, a step including determination of the maximum semblance node (dtn(t_0), τ_0(t_0)),

- and a final step to convert the dtn(t_0) and τ_0(t_0) parameters so as to obtain the velocity V(t_0) and anellepticity η(t_0) laws.

According to a first embodiment of the invention, the processing done is a static NMO correction of seismic traces.

According to a second embodiment of the invention, the processing done is a PSTM migration of seismic traces, the said PSTM migration including a static PSTM NMO correction of the said seismic traces.

A preferred but non-limitative aspect of the process according to the invention relates to the definition of the dtn and τ_0 parameters relative to the velocity V and the anellipticity η so as to make static NMO corrections,

according to $dtn = \frac{8\eta}{1+8\eta}t_0 + \sqrt{\left(\frac{t_0}{1+8\eta}\right)^2 + \frac{x_{max}{}^2}{(1+8\eta)V^2}}$ and $\tau_0 = \frac{t_0}{1+8\eta}$.

Other aspects, purposes and advantages of this invention will become clearer after reading the following detailed description with reference to the attached Figures in which:

- Figure 1a shows the anelliptic offset hyperbola used to make the NMO correction and illustrates the meaning of the parameters τ_0 and dtn;

- Figure 1b represents the DSQR equation of the double anelliptic offset hyperbola of the PSTM migration and illustrates the meaning of the τ_0 and dtn parameters;

- Figure 2 illustrates the effect of the τ_0 parameter of the reflection curve corrected by the NMO correction;

- Figures 3a and 3b represent the analysis volume (t_0, dtn, τ_0) in which the bispectral picking of the dtn and τ_0 parameters according to the invention is made;

- Figure 4 combines each of (V, V_{an}) and (dtn, τ_0) approaches, representing their corresponding bispectral analysis panel;

- Figure 5 shows the correspondence between the (dtn, τ_0) and (V, V_{an}) pairs of NMO correction parameters;

- Figure 6 shows a CMP gather of true seismic traces before the NMO correction and the bispectral picking of the (dtn, τ_0) parameters corresponding to this gather of traces;

- Figure 7 shows the semblance function and velocity and anellipticity functions deduced from the picking of the dtn and τ_0 parameters in Figure 6.

- Figure 8a is a flowchart representing the steps of a first particular embodiment of the invention, namely determination of the V and η parameters to make an NMO correction;

- Figure 8b is a flowchart representing the steps of a second particular embodiment of the invention, namely determination of V and η parameters to do a PSTM migration;

- Figure 9 is a diagram illustrating the different operations carried out in order to determine the V and η parameters to make a PSTM migration.

In general, the method according to the invention is a method for processing records of variable offset seismic traces, and this processing uses the recorded seismic traces to build common midpoint (CMP) trace gathers, and the traces in each gather are subjected to an NMO correction.

In particular, the method according to the invention determines the velocity V and anellipticity η parameters to perform processing including such an NMO correction of the seismic traces of a CMP gather.

For example, the said processing may be:

- an anelliptic NMO correction of the seismic traces;

- an anelliptic PSTM migration which, as we have seen above, jointly applies TZO and migration operations (in the following we will refer to a PSTM NMO correction).

The following description is more specifically applicable to the NMO correction. However, considering in particular the two particular embodiments of the invention that will be described below, we can see that this description is equally applicable to any processing including an NMO correction, particularly processing including a PSTM NMO correction.

Two new parameters dtn and τ_0 are considered in order to specifically determine V and η:

- τ_0 that represents the zero offset travel time in "hyperbolic coordinates" (see Figure 1),

$$\tau_0 = \frac{t_0}{1+8\eta}\eta \qquad \text{Equation (2)}$$

and,

- dtn that represents the NMO correction for the largest offset x_{max} (see Figure 1),

$$dtn = t_{x=x_{max}} - t_{x=0} \text{ namely:}$$

$$dtn = \frac{8\eta}{1+8\eta}t_0 + \sqrt{\left(\frac{t_0}{1+8\eta}\right)^2 + \frac{x_{max}{}^2}{(1+8\eta)V^2}} \qquad \text{Equation (3)}$$

It is important to note that dtn is defined relative to the velocity V and the anellipticity η, while τ_0 is a perfectly anelliptical parameter defined relative to the anellipticity η, independent of V.

Accordingly, the velocity V and anellipticity η parameters may be calculated in accordance with equations (2) and (3), using the following conversion equations (4) and (5):

$$V = \frac{x_{max}}{\sqrt{dtn(dtn+2\tau_0)\frac{t_0}{\tau_0}}} \qquad \text{Equation (4)}$$

$$\text{and } \eta = \frac{1}{8}\left(\frac{t_0}{\tau_0}-1\right) \qquad \text{Equation (5)}$$

Figure 1a shows the anelliptical offset hyperbola used to make the NMO correction and illustrates the meaning of the τ_0 and dtn parameters.

The said "hyperbolic coordinates" are shown in this Figure 1. Their origin on the time axis is taken at the intersection of the said time axis with the asymptote tangent to the said far offset offset hyperbola (see equation (1a)).

Using the (dtn, τ_0) parameters, equation (1a) for the anelliptical offset hyperbola becomes:

$$t = t_0 - \tau_0 + \sqrt{\tau_0^2 + \frac{dtn(dtn+2\tau_0)}{x_{max}^2}x^2} \qquad \text{Equation (6a)}$$

The (dtn, τ_0) parameters defined for the velocity V and anellipticity η are thus used to make the NMO correction $CORR_{NMO} = t - t_0$ to be applied to offset x traces independent of t_0:

$$CORR_{NMO}(x) = -\tau_0 + \sqrt{\tau_0^2 + \frac{dtn(dtn+2\tau_0)}{x_{max}^2}x^2} \qquad \text{Equation (7a)}$$

Therefore, this is a static NMO correction. In other words, the data recorded on a given offset trace will all be corrected in the same way for a (dtn, τ_0) pair, independently of the time at which these data were acquired.

Consequently, the estimate of the velocity and anellipticity parameters is not disturbed by stretching of traces usually observed when dynamic NMO corrections are made.

Similarly using the two parameters (dtn, τ_0), equation (1b) for the DSQR double offset hyperbola for the anelliptic PSTM migration becomes:

$$t = t_0 - \tau_0 + \sqrt{\frac{\tau_0^2}{4} + \frac{dtn(dtn + 2\tau_0)(x - x_m + h)^2}{x_{max}^2}} + \sqrt{\frac{\tau_0^2}{4} + \frac{dtn(dtn + 2\tau_0)(x - x_m - h)^2}{x_{max}^2}} \quad \text{Equation (6b)}$$

Figure 1b shows the DSQR double offset hyperbola of the PSTM migration defined with the (dtn, τ_0) parameters.

In the context of the PSTM migration, x_{max} represents the maximum offset and aperture of the migration.

The (dtn, τ_0) parameters defined relative to the velocity V and anellipticity η are thus used to make the PSTM NMO correction $CORR_{PSTM} = t - \tau_0$ to be applied to the offset x traces independent of τ_0 (equation 7b):

$$Corr_{PSTM}(x) = -\tau_0 + \sqrt{\frac{\tau_0^2}{4} + \frac{dtn(dtn + 2\tau_0)(x - x + h)^2}{x_{max}^2}} + \sqrt{\frac{\tau_0^2}{4} + \frac{dtn(dtn + 2\tau_0)(x - x - h)^2}{x_{max}^2}}$$

Therefore, this is a static PSTM correction. In other words, the se of aperture samples $x - x_m$ of an "iso-offset" cube are offset by the same time for a given (dtn, τ_0) pair.

By analysing the (dtn, τ_0) parameters in several picking times, the method according to the invention can be used in particular to determine the (V, η) parameters necessary for processing including an anelliptic NMO correction of the traces of a CMP gather.

The said process includes the steps presented below in a simplified manner.

During the preliminary step, an analysis volume is defined including several nodes (dtn, τ_0).

The following are performed for all nodes in this volume:

- firstly, according to equation (7a), the static NMO correction of traces in the studied CMP gather, as a function of the values of the dtn, τ_0 parameters at the node considered, the said static correction being valid for any picking time;
- secondly, the semblance as a function of time associated with the correction made in the previous step is calculated.

Finally, the following are determined for each time in the several picking times:

- firstly, the node (dtn, τ_0) used to make an optimum correction, for example with regard to the semblance criterion (this type of criterion typically being used in seismic processing to "measure the horizontality" of reflection curves and to determine the reliability of the picking);
- secondly, the values of the dtn, τ_0 parameters at the said maximum semblance node are converted to values of the velocity V and anellipticity η parameters at the said picking time considered.

The velocity law (in other words all (picking time, V)) pairs and the anellipticity law (all (picking time, η)) pairs are thus defined.

Finally, the NMO correction for all seismic traces may be made using these velocity V and anellipticity η laws in equation (1a) for the anelliptic offset hyperbola.

Similarly, and as will be described in detail later, the (dtn, τ_0) parameters of the static PSTM migration (see equation 7b)) may also be checked. The velocity V and anellipticity η laws are then determined and may be used to make the PSTM migration in the DSQR equation (1b) for the double anelliptic offset hyperbola.

Figure 2 illustrates the effect of the parameter τ_0 (and therefore the anellipticity η according to equation (2) on the curvature residues after the NMO correction.

Note that the vertical time scale of the curve in Figure 2 is exaggerated so that this effect can be clearly understood.

Three curves are shown in Figure 2, for which the dtn parameter is fixed to the correct value and the parameter τ_0 is assigned different values.

The central curve shows the case in which τ_0 is equal to its correct value τ_{01}, in other words when the corresponding anellipticity η_1 is equal to its true value η_{true}. As expected, the corrected reflection curve is then horizontal.

The upper curve shows the case in which τ_0 is equal to a value τ_{02} less than its correct value τ_{01}, the corresponding anellipticity η_2 being greater than its true value η_{true}.

The lower curve represents the case in which τ_0 is equal to a value τ_{03} greater than its true value τ_{01}, the anellipticity η_3 being less than its true value η_{true}.

Note that these lower and upper curves show that the "horizontality" of the corrected reflection curve is

acceptable at near offset ($x \approx 0$) and at far offset ($x \approx x_{max}$).

On the other hand, significant curvature residues are observed when the offset x no longer tends towards one of these limiting values 0 and x_{max}. In particular, particularly significant residues are observed for an offset x centred in the middle of the offsets range.

For example, and as is shown in Figure 2, when τ_0 is equal to τ_{02}, an RMOτ_{02} residual correction must be made to the offset traces $x_{RMO}\tau_{02}$. Similarly, when τ_0 is equal to τ_{03}, a residual correction RMOτ_{03} must be made to offset traces $x_{RMO}\tau_{03}$.

Due to these significant curvature residues, the offsets range can be used almost in its entirety in order to determine the anellipticity η.

Therefore, setting parameters in (dtn, τ_0) for the NMO correction make it possible to use available data for all offsets (x between 0 and x_{max}) in determining the anellipticity η.

As has already been mentioned, this is not the case for NMO corrections for which parameters have been set with V and η for which the estimate of the anellipticity η is made essentially using far offset data.

Thus, the effect of the new anelliptic parameter τ_0 is distributed on all offsets, unlike the anellipticity η that only affects far offsets. Therefore, the "behaviour" of the parameter τ_0 gives a better constraint on anellipticity values.

As already mentioned above, the optimum dtn and τ_0 parameters are determined within a 3D analysis volume (t_0, dtn, τ_0).

Several nodes (dtn, τ_0), in other words several pairs of dtn, τ_0 parameters for which values are known, are considered in the said analysis volume.

Nodes are usually regularly spaced from each other, by an increment Δdtn on the dtn axis and an increment $\Delta\tau_0$ on the τ_0 axis.

Minimum values dtn_{min}, τ_{0min}, t_{0min} and maximum values dtn_{max}, τ_{0max}, t_{0max} of the τ_0 and t_0 respectively provide a means of defining the limits of the said analysis volume.

Advantageously, plausible values of the velocity parameter V and the anellipticity parameter η may be used to define a corridor $[dtn_{min}(t_0), dtn_{max}(t_0)]$, $[\tau_{0min}(t_0), \tau_{0max}(t_0)]$ inside the said analysis volume.

This corridor restricts the analysis volume and therefore the number of nodes (dtn, τ_0) that have to be considered to determine the optimum pair (dtn, τ_0).

Although use of the said corridor is beneficial for the efficiency of the process according to the invention, it also provides a means of constraining solution towards the right phenomena, without needing to consider incompatible (dtn, τ_0) (and therefore V, η)) pairs, for example related to multiple reflections or miscellaneous interference phenomena.

Figures 3a and 3b represent the said analysis volume (t_0, dtn, τ_0) in the context of an example of true seismic data processing during an NMO correction done according to the process according to the invention.

Figure 3a represents three 2D panels a, b and c of the analysis volume:

- panel a is a panel (dtn, τ_0) with constant t_0;
- panel b is a panel (dtn, t_0) with constant τ_0;
- panel c is a panel (τ_0, t_0) with constant dtn.

Figure 3b diagrammatically shows the 3D analysis volume (t_0, dtn, τ_0) and three intersections with this volume along three planes with constant t_0, τ_0, dtn respectively, each of these intersections being projected onto the corresponding side a, b or c in Figure 3a.

Panels (dtn, τ_0) with constant t_0 (panel a in the above example) are panels in which the bispectral picking of the dtn and τ_0 parameters is made, for example according to the maximum NMO correction semblance criterion, for the considered picking time t_0.

The $[dtn_{min}(t_0),\ dtn_{max}(t_0)]$ $[\tau_{0min}\ (t_0)\ \ \tau_{0max}\ (t_0)]$ corridor mentioned above for the effective analysis inside the analysis volume is also shown in Figure 3a (lighter zone on each panel).

The seismic data sampling time step Δt_0 defines the difference between two successive picking times (times for which the maximum associated semblance node (dtn, τ_0) is determined) and therefore the number of bispectral picking panels to be considered.

Automatic picking also provides a means of extracting the dtn, τ_0 parameters at a density that is greater when the Δt_0 increment between picking times is small.

Sampling of the analysis parameters dtn and τ_0 is directly related to the resolution of the seismic

exploration; dtn and τ_0 effectively have the same dimensions as seismic records.

The systematic search for the maximum semblance, conventionally known in itself, provides a means of determining the (dtn, τ_0) pair providing best focus, for a given picking time t_0.

Parabolic interpolations about the values of nodes (dtn, τ_0) can also provide a means of evaluating values of the dtn, τ_0 parameters between the different nodes that have actually been picked. And in particular this type of evaluation makes determination even more precise (in contrast to determination limited to nodes in the corridor) of the dtn, τ_0 parameter pair maximising the semblance function.

Finally, the velocity V and anellipticity η parameters are determined, always for the picking time t_0 considered, by using the above mentioned conversion equations (4) and (5).

Figure 4 shows the comparison between the two approaches (V, V_{an}) and (dtn, τ_0), by representing the bispectral picking panel for each, for a given picking time.

The figure at the right illustrates the conventional approach (V, V_{an}) for which the two axes are the velocity axes (the anellipticity η being related to the ratio of these two velocities according to $\eta = \frac{1}{8}\left(\frac{V_{an}^4}{V^4} - 1\right)$).

The left figure illustrates the approach (dtn, τ_0) according to the invention for which the two axes are time axes.

It is important to note from the study in Figure 4 that the dtn and τ_0 parameters appear to be decorrelated. This "decorrelation" is striking when the two approaches are compared, spreading of the (dtn, τ_0) spectrum actually being much narrower than spreading of the (V, V_{an}) spectrum.

Therefore the picking made in the context of the (dtn, τ_0) approach according to the invention is more precise than the approach carried out in conventional methods.

Furthermore, this decorrelation enables filtering of the dtn and τ_0 pickings separately, while keeping NMO corrections. This is not the case for the V and η parameters for which a reduction in one of the parameters must necessarily be compensated by an increase in the other and vice versa.

And due to interpolations and individual filtering of parameters according to the invention, dtn and τ_0, it is then possible to perform simultaneous interpolation and filtering of the standard NMO correction parameters V and η.

Figure 5 shows non-linear correspondence according to equations (4) and (5) mentioned above, between the pair of time parameters (dtn, τ_0) and the pair of velocity parameters (V, V_{an}).

Figure 6 shows, from left to right:

- a CMP gather of real seismic traces before NMO correction;

- the picking of the dtn parameter corresponding to this gather of traces;

- the picking of the τ_0 parameter corresponding to this gather of traces.

The straight line $\tau_0 = t_0$ on the picking of the parameter τ_0 at the right in Figure 6, corresponds to the purely hyperbolic reflection curves.

From right to left, Figure 7 represents the semblance function and the velocity V and the anellipticity η functions (see equation (4) and (5)) deduced from the picking of the dtn and τ_0 parameters shown in Figure 6.

On this example of real seismic data processing, it can be seen that the values of V and η obtained generally corresponding to a semblance of more than 40%.

The following description contains details of two particular embodiments of the invention.

The first of these modes relates to a process for determining optimum parameters to make an anelliptic NMO correction to the traces of a CMP gather (see the different steps shown in the flowchart in Figure 8a).

With reference to Figure 8a, this first embodiment includes an initialisation step 1a during which the following operations are carried out in sequence:

- determination of the limits of the analysis volume $[dtn_{min}, dtn_{max}]$ $[\tau_{0min}, \tau_{0max}]$ $[t_{0min}, t_{0max}]$;

- calculation of NMO corrections $CORR_{NMO}$ (equation (7a)) for all offsets and for all nodes (dtn, τ_0) included in the analysis volume;

- delimitation inside the analysis volume of the corridor $[dtn_{min}(t_0), dtn_{max}(t_0)]$ $[\tau_{0min}(t_0)\ \tau_{0max}(t_0)]$ of plausible velocity and anellipticity values.

Once the initialisation step 1a has been carried out, a step 2a to calculate velocity $V(t_0)$ and anellipticity $\eta(t_0)$ laws is performed for each gather of CMP traces.

This step 2a comprises:

- a first operation 3a carried out for each node (dtn, τ_0) in the corridor defined in the initialisation step 1a, during which the following operations are carried out in sequence for each picking time t_0:
  - application of static NMO corrections $CORR_{NMO}$ for all offsets along the corridor, precalculated during the initialisation step 1a;
  - calculation of the semblance function on data corrected along the corridor using a time window appropriate to the dominant wavelet;
  - summation ("stack" calculation) of data corrected along the corridor (only near offset data can be used advantageously for this purpose);
- a second operation 4a carried out for each picking time t_0 (the said times being at intervals of Δt_0 between $[t_{0min}, t_{0max}]$ during which the following operations are carried out:
  - search for maximum semblance in the $[dtn_{min}(t_0), dtn_{max}(t_0)]$ $[\tau_{0min}(t_0)\ \tau_{0max}(t_0)]$ corridor of the bispectral panel (dtn, τ_0);
  - check the fact that the position in (dtn, τ_0) at the maximum semblance corresponds to a summation extreme value for the same values dtn and τ_0;
  - creation of the $dtn(t_0)$, $\tau_0(t_0)$ and semblance (t_0) series;

- a third operation 5a designed to select and adjust the pickings obtained, during which the following operations are carried out:

- increasing sort of the semblance series (t_0);

- validation of pickings dtn and τ_0 for which the distance in time to the highest semblance pickings is greater than a predefined value;

- adjustment of picking dtn and τ_0 values validated by parabolic interpolations using surrounding values;

- retention of picked, validated and adjusted values if it is possible to calculate the Dix interval velocities with the pickings with the highest similarities.

- a fourth operation 6a designed to use equations (3) and (4) to convert picked, validated and adjusted and retained values of dtn and τ_0 during operation 5a, into velocity V and anellipticity η laws.

The velocity V and anellipticity η laws as a function of time are thus perfectly determined. The anelliptical NMO correction of seismic traces in the CMP gather can thus be done precisely.

The second particular embodiment of the invention relates to a process for determination of optimum parameters for anelliptical PSTM migration of traces in a CMP gather.

This second embodiment may be included in a generalisation of the first mode discussed above.

As has already been demonstrated, the use of the (dtn, τ_0) parameters enables static PSTM NMO corrections (see equation (7b)).

In the context of a PSTM NMO correction, this application has the same advantages as previously discussed for the NMO obliqueness correction.

More precisely, it will be noted that the first embodiment is only a special case of the second embodiment corresponding to the case of a zero migration aperture.

With reference to Figure 8b, the second embodiment includes an initialisation step 1b during which the following operations are carried out in sequence:

- determine the limits of the analysis volume $[dtn_{min}, dtn_{max}]$, $[\tau_{0min}, \tau_{0max}]$, $[t_{0min}, t_{0max}]$;

- calculate NMO corrections $CORR_{PSTM}$ (equation (7b)) for all nodes (dtn, τ_0) included in the analysis volume and for all migration offsets inside the migration aperture;

- delimitation of plausible velocity and anellipticity values inside the analysis volume of the corridor $[dtn_{min}(t_0), dtn_{max}(t_0)]$ $[\tau_{0min}(t_0)\ \tau_{0max}(t_0)]$.

Once this initialisation step 1b has been done, the said first embodiment creates a step 2b to calculate the velocity $V(t_0)$ and anellipticity $\eta(t_0)$ laws for each gather of CMP traces.

This step 2b comprises:

- a first operation 3b done for each node (dtn, τ_0) of the corridor defined during the initialisation step 1a, during which the following are carried out in sequence:

  - for each offset class, operations for:

    - application on all midpoints inside the migration aperture along the corridor, of static

corrections $CORR_{PSTM}$ precalculated during the initialisation step 1b;

- summation of corrected midpoints along the corridor.

- for each picking time t_0, operations to:

- calculate the semblance function on corrected data along the corridor using a time window appropriate to the dominant wavelet;

- summation (stack calculation) of data corrected along the corridor (only data with small offsets can be used advantageously for this purpose):

- a second operation 4b carried out for each picking time t_0, similar to the operation 4a described above, to create the $dtn(t_0)$, $\tau_0(t_0)$ and semblance t_0 series;

- a third operation similar to operation 5b described above, designed to select and adjust the pickings obtained;

- a fourth operation 6b similar to operation 5a described above, designed to convert values of dtn, τ_0 into velocity V and anellipticity η laws.

The velocity V and anellipticity η laws as a function of time are thus perfectly determined. And the PSTM migration of seismic traces in the CMP gather may thus be done accurately.

Figure 9 illustrates the second embodiment of the invention that has just been described.

Seismic data are initially grouped into iso-offset cubes.

As has just been described, NMO corrections $CORR_{PSTM}$ are applied (see first operation in step 3b) for each offset class (namely for each iso-offset cube) on all

midpoints. The arrow marked with the MIG label in Figure 9 illustrates this operation.

The midpoints thus corrected are then summated during a second operation in step 3b, the arrow labelled STACK in Figure 9 illustrating this operation.

These two MIG and STACK operations are specific to the second embodiment of the invention (PSTM migration).

The following operations are performed in the context of each of the two embodiments discussed (the NMO obliqueness correction, as we have described, corresponding to the special case of a PSTM migration with zero migration aperture).

The semblance is then calculated for each picking time (second operation in step 3a for the NMO correction only, third operation in step 3b for the PSTM migration), the arrow labelled "semblance" in Figure 9 illustrating this operation.

Obviously, the MIG, STACK and semblance calculation operations are implemented for each node (dtn, τ_0).

The "automatic bispectral picking" mentioned in Figure 9 corresponds to picking of maximum semblance parameters (dtn, τ_0) for each picking time t_0 (operations 4a, 4b in Figures 8a, 8b respectively). The arrow labelled MAX illustrates the search for the maximum semblance.

Finally, the pickings of the picked parameters (dtn, τ_0) are converted into velocity V and anellipticity η laws (operations 6a, 6b in Figures 8a, 8b and arrow labelled CONV in Figure 9).